Atmospheric Extinction in Solar Tower Plants

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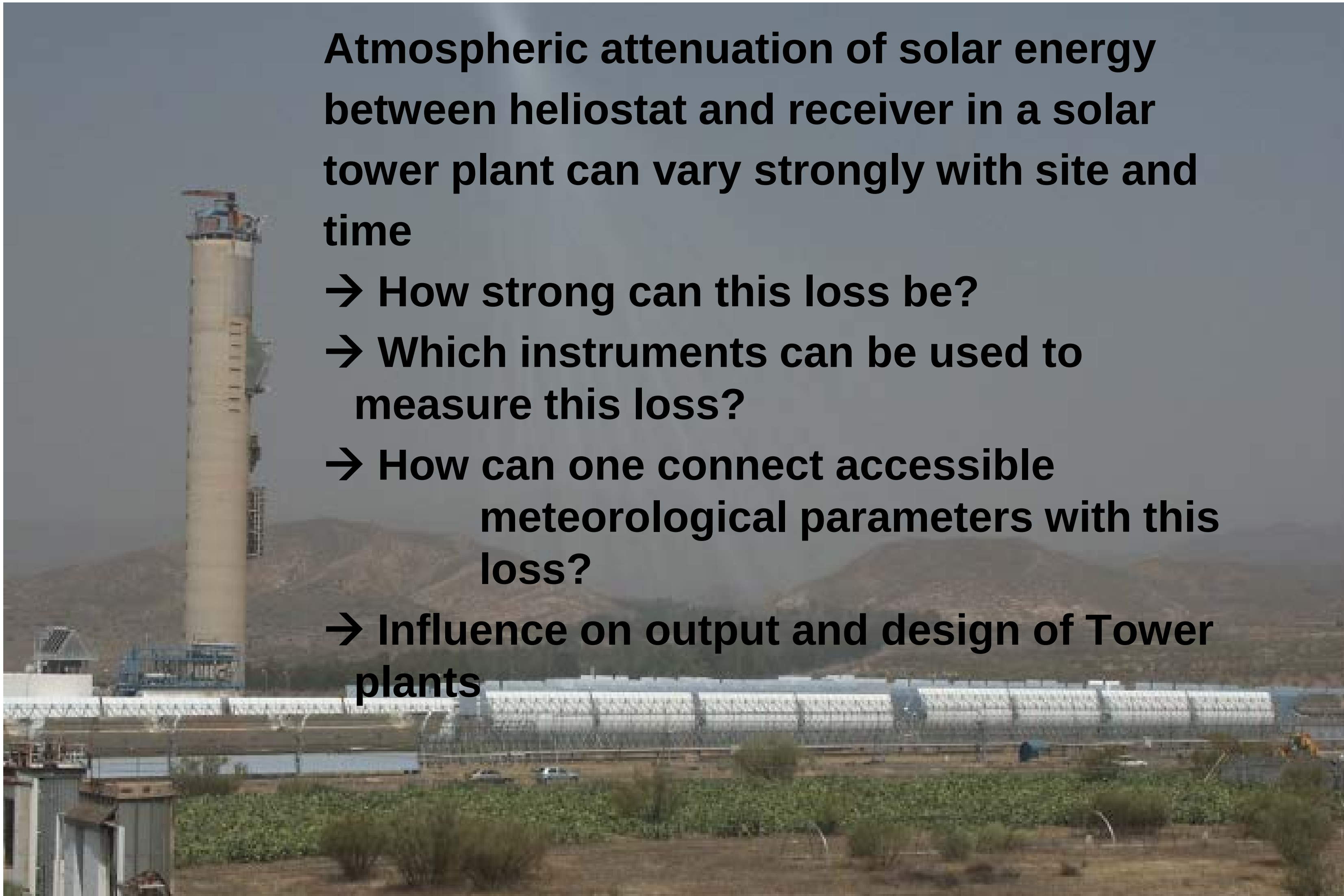
1. Motivation



Atmospheric attenuation of solar energy between heliostat and receiver in a solar tower plant can vary strongly with site and time

→ How strong can this loss be?

→ Which instruments can be used to measure this loss?

→ How can one connect accessible meteorological parameters with this loss?

→ Influence on output and design of Tower plants

2. Instrumentation

Available instruments to determine horizontal transmittance:

2 Vaisala FS11 scattermeters

- forward scattering of beam in small air volume
 → **Only scattering considered!**
- 875 nm
- Accuracy MOR (manufacturer) = ± 3 %

Optec LPV-4 transmissometer

- transmittance of beam over path distance (~500 m at PSA)
 → **Scattering AND absorption considered!**
- 532 nm
- Accuracy MOR (manufacturer) = ± 3 %
 Corresponds to 6 % for T_{1km}
 → **the larger the path distance, the higher the accuracy!**

libRadtran

Grimm EDM 164 particle counter + LibRadtran Simulation

- 31 channels to count particles between 0.25 and 32 µm
 + sensors for temperature, pressure, humidity

- Library for radiative transfer for calculations of solar and thermal radiation in the Earth's atmosphere [Mayer and Kylling,2005]

Measurements of DNI

ground level + top of tower

3. Extinction Model

Four methods to determine horizontal transmittance :

FS11 Scattermeters at surface (SUR)

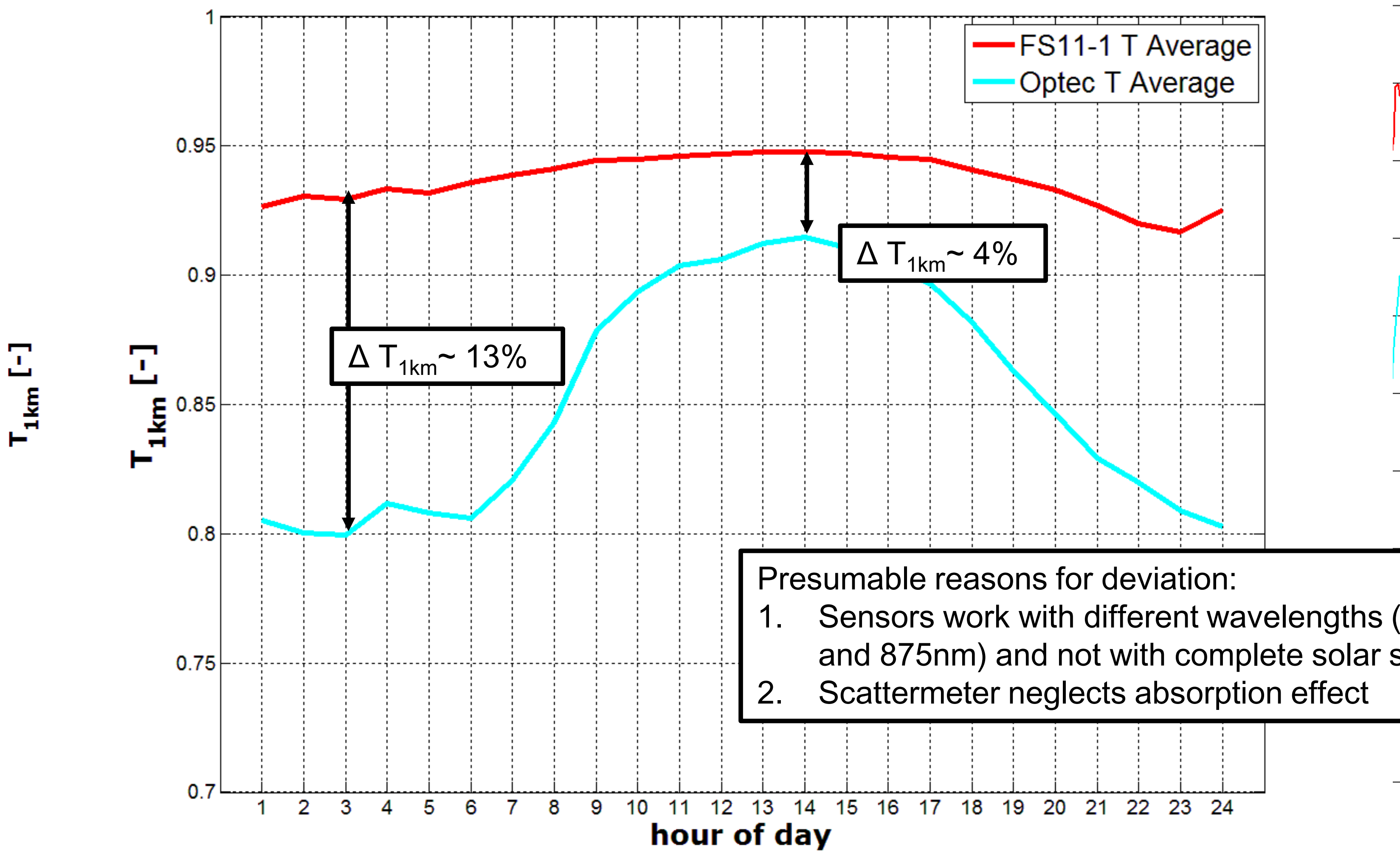
Optec Transmissometer at SUR

Grimm particle counter at SUR + LibRadtran

DNI measurements at SUR + top of tower

intercomparison

4. First results - Scattermeter vs. Transmissometer



Presumable reasons for deviation:

1. Sensors work with different wavelengths (532nm and 875nm) and not with complete solar spectrum
2. Scattermeter neglects absorption effect

4. First results - Scattermeter vs. Transmissometer

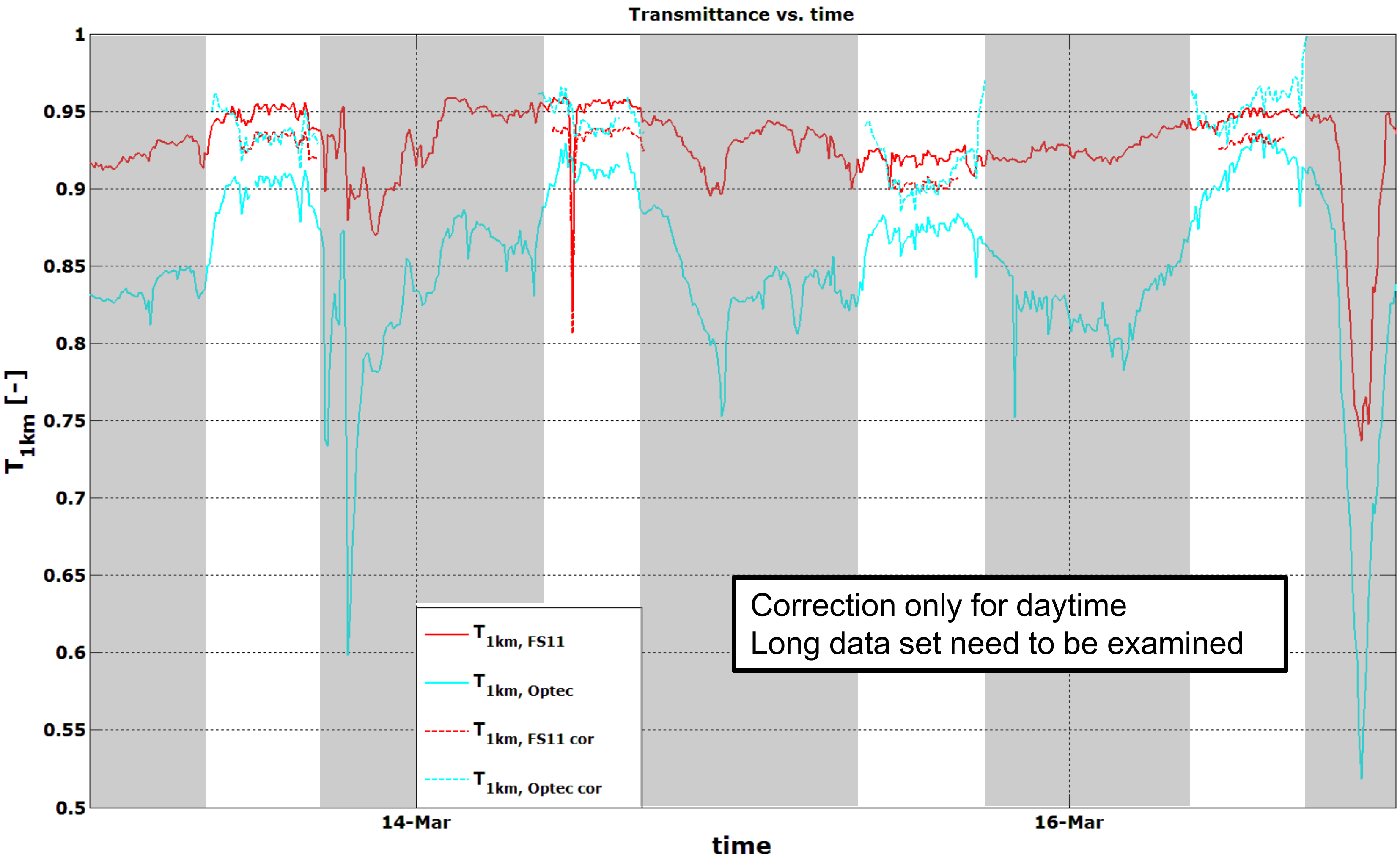
Spectral and Absorption Correction necessary!

→ Developed procedure using radiative transfer:

1. Simulate spectral DNI at ground level with LibRadtran (on-site data input for temperature, pressure, relative humidity and AOD from nearby AERONET and weather station)→ input for Step 2
2. Simulate spectral transmittance after photons passed horizontally through an imaginary homogeneous layer
3. Calculate absorption and scatter contribution as well as spectral distribution of the transmittance

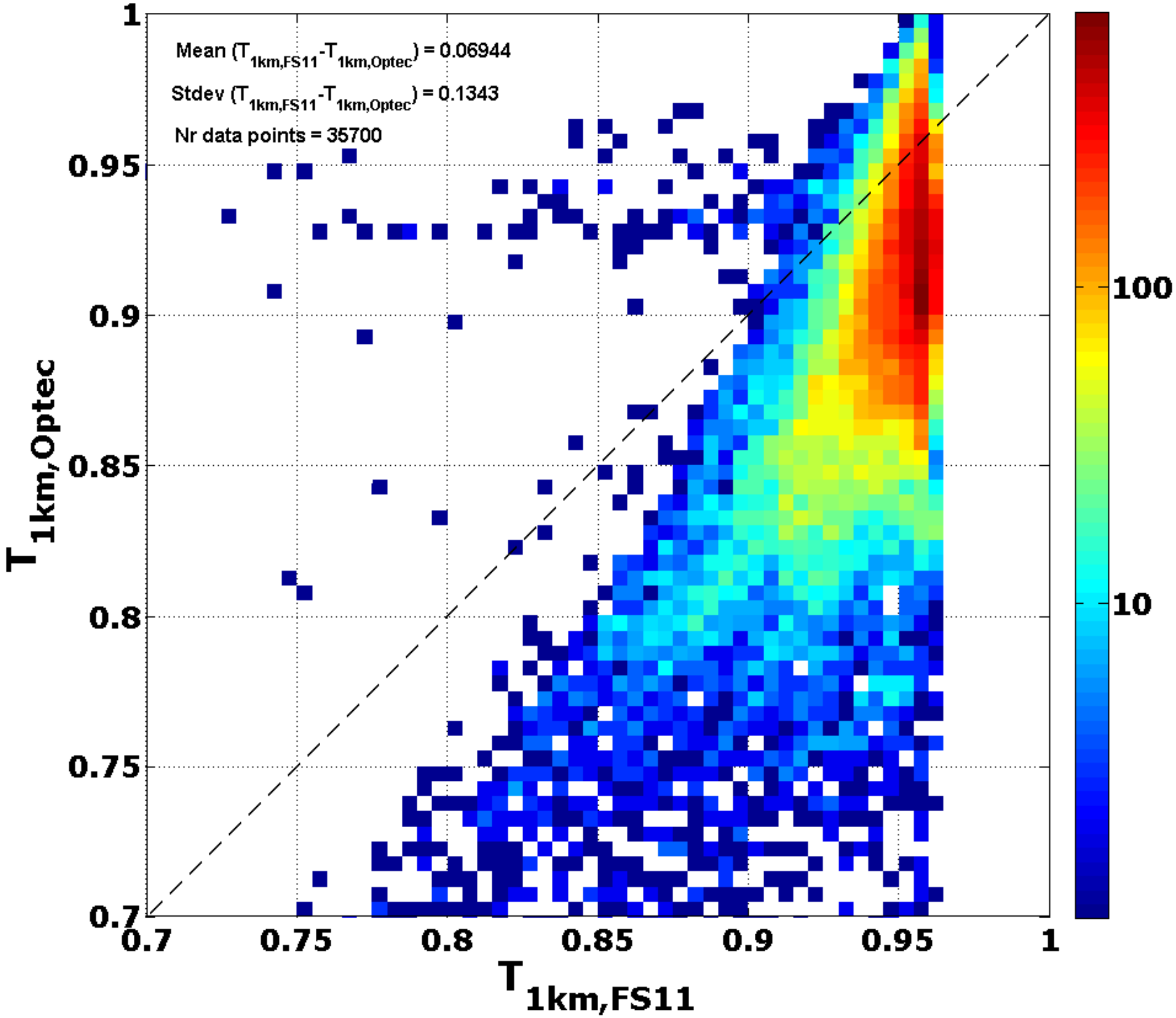
→ Spectral correction of signal of the Optec transmissometer
→ Spectral and absorption correction of signal of FS11 scattermeter

4. First results - Scattermeter vs. Transmissometer



Correction only for daytime
Long data set need to be examined

4. First results - Scattermeter vs. Transmissometer

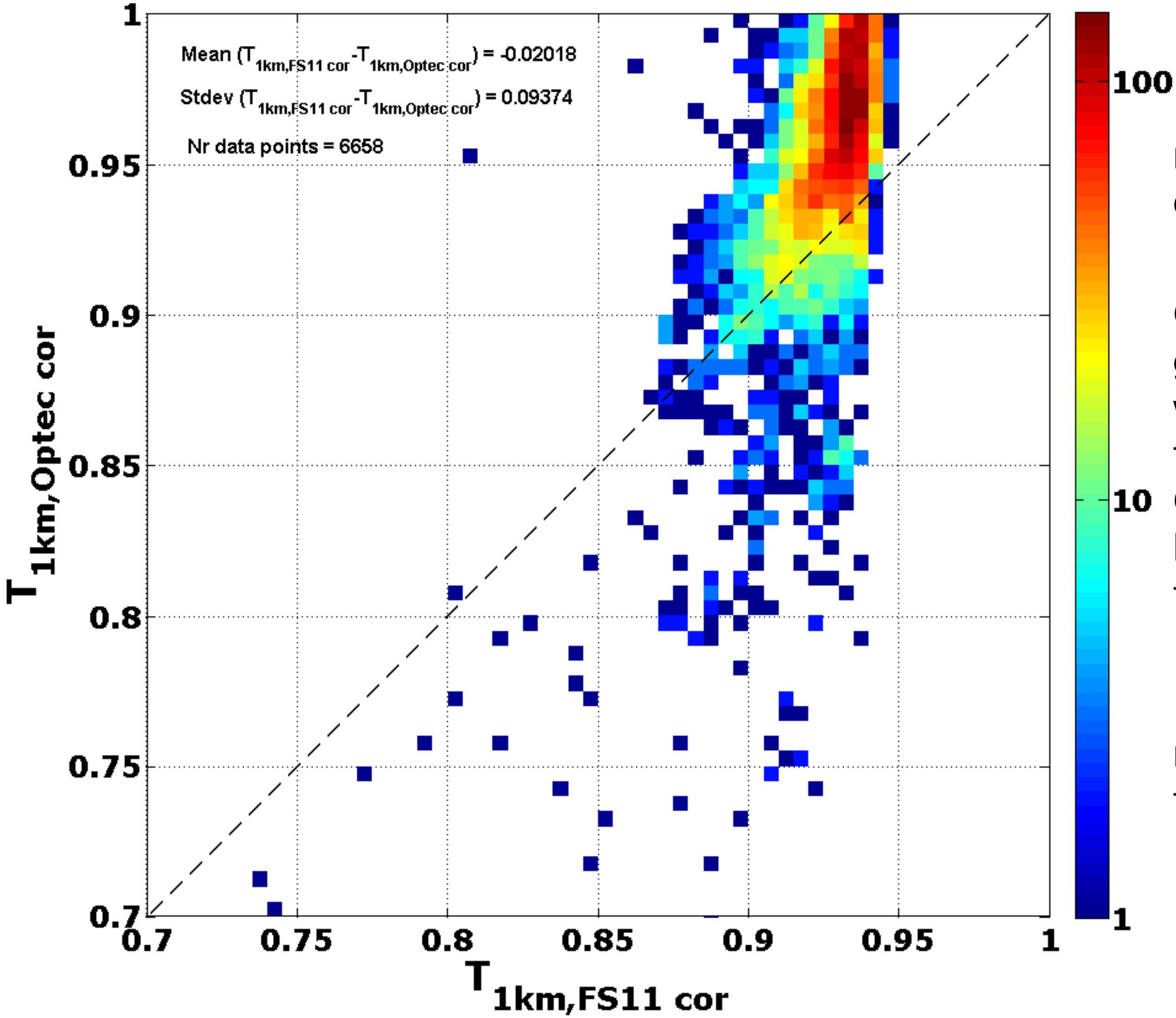


Dataset May 2013- May 2014

10 min time resolution

Correction reduces mean difference between both sensors + standard deviation

4. First results - Scattermeter vs. Transmissometer



In wintertime FS11 and Optec measurements more similiar due to clearer atmosphere

Optec correction factor generally higher during wintertime → correction tends to over-amplify the results for Optec measurements → can be improved by including real-time aerosol load information

Refinement of correction method has to be conducted to optimize correction result

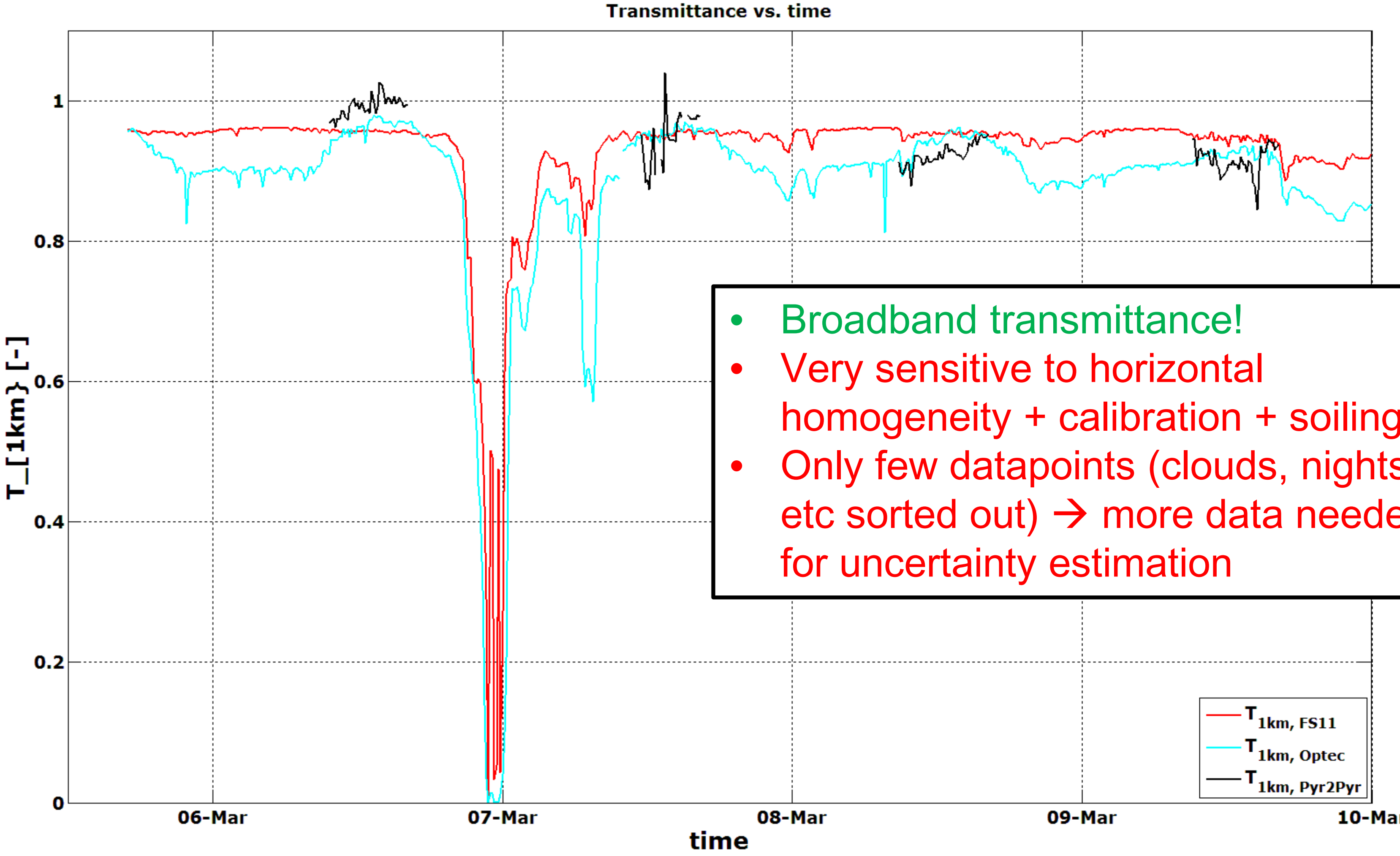
4. First results – 2 Pyrheliometer

Method:

- Collect DNI data at two different heights (0 and 90m over ground)
- Prepare data (calibrate pyrheliometers relative to each other: mean deviation of pyrheliometers next to each other ~ 1.08 W/m², sort out cleaning events)
- Sort out clouds (using thresholds for DNI (<100 W/m²) and Linke turbidity (>3) and absolute gradient of LT (>0.06 for 10min time resolution))
- Sort out nights (elevation of sun must be over 20° ← must be evaluated with plant simulation)
- Correct distance between sensors for airmass:

  Towerheight = real towerheight * airmass

4. First Results – Comparison of methods



- Broadband transmittance!
- Very sensitive to horizontal homogeneity + calibration + soiling
- Only few datapoints (clouds, nights etc sorted out) → more data needed for uncertainty estimation

4. First results – LibRadtran + Grimm

Method:

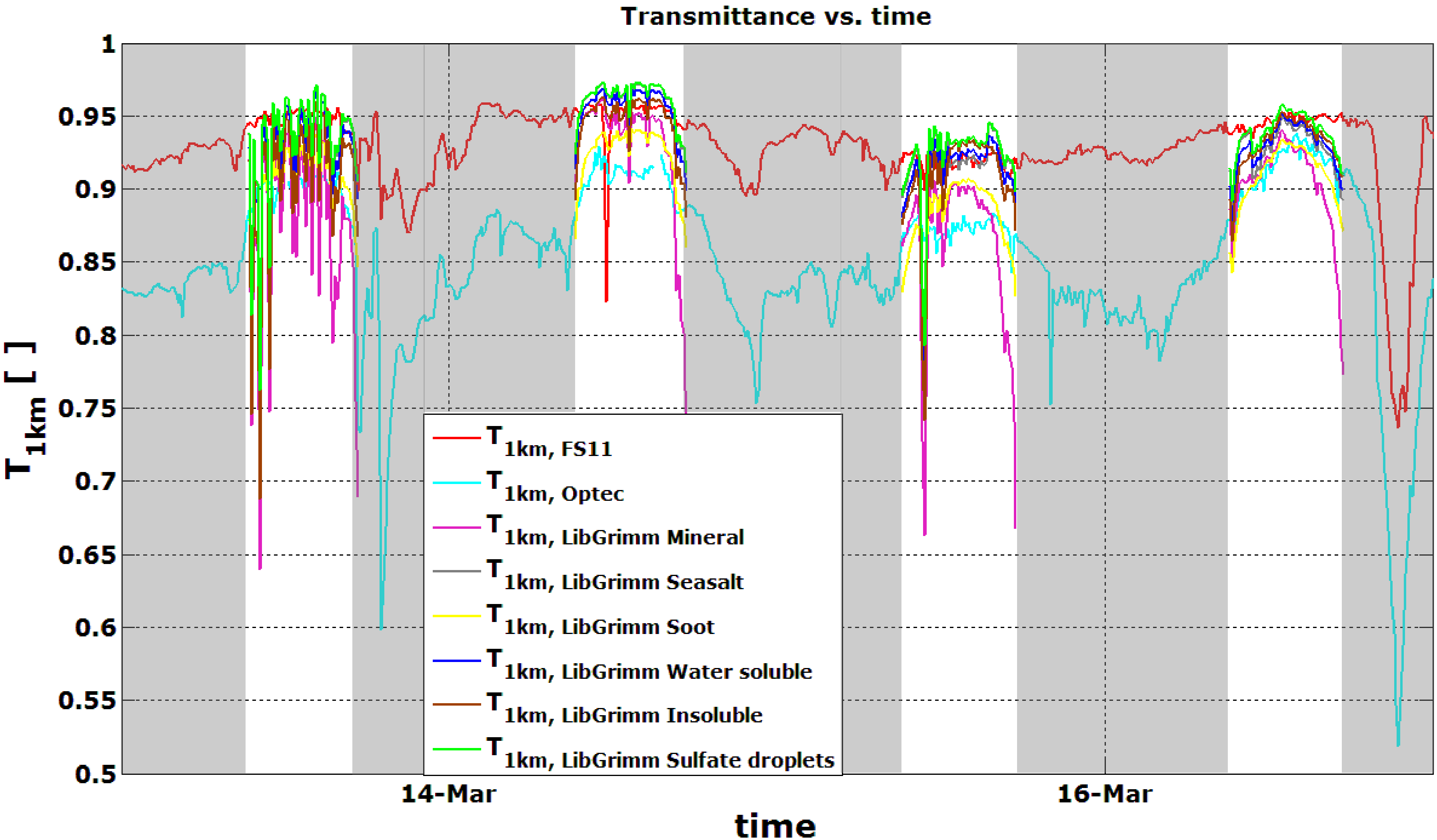
1. Simulate optical properties of different aerosol types for all size bins of the Grimm particle counter using Mie calculations
2. Simulate spectral DNI at ground level using input of temperature, pressure, relative humidity and AOD from AERONET and particle counter
3. Simulate radiative transfer of photons through an homogeneous layer containing measured particle distribution, temperature, pressure and relative humidity

libRadtran

Challenges and assumptions:

1. Present aerosol type not known → sensitivity study concerning aerosol types of OPAC database (Hess et al., 1998)
2. Spherical particles are assumed
3. So far no multiple scattering considered

4. First results – LibRadtran + Grimm



5. Conclusion

1. All 4 methods are promising options to measure atmospheric extinction
2. A correction procedure was developed to enhance the measurements of the scatter- and transmissometer. This method is available for resource assessment
3. The method using 2 pyrheliometers in different heights need to be evaluated after collection of a longer timeseries
4. Combining measured particle size distributions with radiative transfer simulations turn out to provide reliable results for broadband extinction. More information about on-site present aerosol types will enhance the method.

6. Outlook

- Comparison of methods for longer time series
- Mounting of scattermeter and particle counter at another site with higher dust loads
- Lidar measurements in comparison to sunphotometer to determine height profile of extinction
- Formulation of model to introduce time and site specific input of transmittance in existing CSP simulation tools
- Evaluation of influence of transmittance using existing and modified CSP simulation tools
- Documentation

Thank you for your attention!

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